HEAT EXCHANGER ASSEMBLY WITH DISSIMILAR METAL CONNECTION CAPABILITY

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based on and claims priority from U.S. Patent Application Number 09/356,188 filed on July 16, 1999.

FIELD OF THE INVENTION

The present invention relates to heat exchangers used to cool various flowing fluids. More particularly, the invention relates to a heat exchanger assembly for use in cooling engine oil, transmission fluid, or exhaust by passing a cooling fluid around or through the exchanger, particularly one utilizing two different metals in its construction.

BACKGROUND OF THE INVENTION

Heat exchangers are used to transfer heat absorbed by a first fluid to a second cooling fluid. Either fluid may flow through passages located within the exchanger or around the passages, passing through openings extending through the exchanger that are spaced about the passages and are defined by a plurality of fins extending outwardly around the passages. Prior art heat exchangers have been constructed in a multitude of arrangements to expose the maximum surface area on the passages and the surrounding fins to allow the greatest heat transfer to occur between the first and second fluids.

Older heat exchangers consist of arrangements of tubular passages having radially extending fins spaced from one another and attached to the passages in a permanent relationship. Heat exchangers of this type, while effective in cooling the heated first fluid flowing from the engine, are difficult to maintain and repair due to the unitary construction of the heat exchanger, as this construction necessitates the total disassembly of the exchanger to repair the exchanger. Disassembling these types of exchangers requires that the permanent connections between the components of the heat exchanger be undone, a process which is both time consuming and expensive.

More recent developments with regard to fluid heat exchanger design have resulted in the creation of modular heat exchangers, such as that disclosed in Dierbeck U.S. Patent No. 5,303,770. In this heat exchanger, the exchanger is comprised of a number of modules that are positioned against one another to form the modular heat exchanger. The individual modules can be releasably connected to one another to form

the heat exchanger, removing the need for permanent welded, brazed, or soldered connections between the modules. In this arrangement, the modules are connected to one another by a set of tie rods extending through the ends of each of the modules to rigidly, but removably, secure the modules to one another to form the heat exchanger. Alternatively, similarly to prior art exchangers, the individual modules can also be welded to each other or otherwise joined to form permanent assemblies of specified numbers of modules used to form the heat exchanger.

Each module disclosed in the above-identified patent consists of an elongate, rectangular extruded aluminum block including longitudinally extending oval-shaped passages and a series of outwardly extending fins spaced around the passages along the exterior of the block on the wide face thereof. The module also includes a flat face portion at either end in which no fins are disposed. A lateral opening is located in each face portion of the module that perpendicularly intersects opposite ends of the longitudinal passages. The openings cooperate with similar openings on adjacent modules to form a pair of fluid accumulation chambers. Each fluid accumulation chamber is closed at one end and open at the other end to provide an inlet or an outlet connection for fluid flow through the heat exchanger. In this arrangement, the heated first fluid enters the exchanger through an inlet end piece secured over the open end of one of the fluid accumulation chambers in the heat exchanger. Upon entering the chamber, the fluid is dispersed to flow in parallel through the longitudinal passages of each modular element in the exchanger. The second cooling fluid passes through transverse flow passages between the fins disposed about the longitudinal passages and cools the heated fluid flowing within the passages. Upon exiting the passages, the now cooled first fluid enters the fluid accumulation chamber on the opposite end and is recirculated back to the source of the first fluid through an outlet end piece secured over the open end of the other accumulation chamber.

In the above-identified patent, the inlet and outlet end pieces are secured to the ends of the heat exchanger by the tie rods that also hold the modules together. Alternatively, the modules may be welded to each other. When welded together, the end pieces must be formed of the same metal as the modules to insure weld integrity and avoid potential problems of weld failure resulting from differential thermal expansion in

dissimilar metals. Therefore, to avoid these problems, the inlet and outlet end pieces, as well as any other attachments connected to the modular elements, should be formed of aluminum to insure that the welded connections will not fail. This necessarily limits the application of the modular heat exchanger comprised of the extruded aluminum block modules to uses in which any necessary attachments welded to the heat exchanger, and any other elements welded to those attachments, can be formed of the same metal as the exchanger elements.

In a situation where a modular heat exchanger of this type is placed within an enclosure to utilize a fluid flowing through the enclosure as the cooling fluid, the heat exchanger must be able to be fixed within the enclosure to openings in a wall or walls of the enclosure in a secure and leak-proof manner. This normally requires welded or brazed connections made between the wall and the exchanger. However, if the end pieces welded to the heat exchanger are aluminum and the enclosure is formed of a different metal, welding the two dissimilar metals may be impossible or may not provide a reliable leak-proof connection due to the thermal expansion differential between the dissimilar metals.

To overcome this problem, certain prior art patents have disclosed methods for securing elements of a heat exchanger made from dissimilar metals to one another that form welded connections between the elements that greatly reduce weld failure.

U.S. Patent No. 2,368,391 discloses a method of fastening copper tubes within steel headers or tube plates. In this method, a copper tube is brazed to a steel sleeve that forms a protective layer around the copper tube. The steel sleeve is then welded to the steel header to connect the copper tube to the header. As the weld is formed between a sleeve and a header formed of the same metal, the weld made between the sleeve and the header does not have any thermal expansion problems that would cause premature failure of the weld. Also, when the steel sleeve is welded to the steel header, the steel sleeve around the copper tube prevents the tube from being damaged by the heat generated during the welding process.

U.S. Patent No. 4,034,802 also discloses a heat exchanger, namely, a radiator, that is formed of aluminum and to which are connected pipes formed of a dissimilar

metal. The pipes are retained in connection with the aluminum radiator through the use of sleeves placed around the end of the pipes that contact and engage the interior of the conduit in the aluminum radiator to which the pipes are attached. The sleeves are attached to both the radiator and to the pipe by frictional forces generated by the insertion of the pipe into the sleeve within the radiator. The necessary frictional forces are generated by sets of threads disposed on the interior and exterior surfaces of the sleeve that contact the conduit and pipe. The insertion of the pipe flexes the sleeve outwardly, engaging the exterior threads with the conduit, and securing the sleeve within the conduit. The interior threads engage a complementary thread on the pipe exterior when the pipe is inserted into the sleeve to hold the pipe within the sleeve.

While providing reliable dissimilar metal connections, in both of these prior art patents, the methods of attachment of the pieces of dissimilar metals include the attachment of a connecting element to each of the items to be attached. In the former, the steel sleeve must be brazed to the copper tube before welding to the header, and in the latter, the pipe must be threaded into the connector sleeve in order to engage the sleeve with the conduit. Thus, each prior art method requires that the connecting element be separately connected to each item. This places a large amount of stress on the connecting element and is also an unnecessary duplication of effort. Therefore, it is desirable to develop a heat exchanger assembly that includes a dissimilar metal connection that is formed on the exchanger in a single step to avoid any undesirable stress on the connection element.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a novel heat exchanger assembly and method for attaching an end piece formed from one metal to a heat exchanger formed from a dissimilar metal.

It is another object of the present invention to provide a heat exchanger assembly having this dissimilar metal connection that is formed of easily dissassembleable components.

It is still another object of the present invention to provide a heat exchanger assembly with a dissimilar metal connection that can be quickly modified for use in a variety of different applications.

The present invention is a heat exchanger designed for use as an fluid cooler that includes a dissimilar metal enclosure connection. The body of the heat exchanger can be of unitary construction, or may be comprised of individual modules similar to those disclosed in U.S. Patent No. 5,303,770, which is herein incorporated by reference. The modules are generally rectangular extruded blocks that include a pair of longitudinal passages extending through the block and a number of V-shaped grooves extending along the wide faces of the block. A plurality of slots are cut transversely into the grooves to form fins disposed about the wide faces of the block along the entire length of the block.

Each block also includes a pair of grooved face portions located at either end of the block in which no slots are cut. The face portions each have a lateral opening that extends through the face portion and intersects the longitudinal passages. The openings communicate with similar openings disposed within the face portions of adjacent blocks when a number of blocks are connected to form the heat exchanger. In such an arrangement, the lateral openings form a fluid accumulation chamber along each side of the exchanger. These fluid accumulation chambers make up flow inlet and outlet connections for the exchanger.

To prevent the fluid flowing through the longitudinal passages from leaking around the edges of the lateral openings and between adjacent blocks, a counterbore is circumferentially disposed about each end of the lateral openings. In the counterbore is disposed a sealing arrangement which engages a complimentary structure about the lateral opening on an adjacent block to effectively seal the lateral openings.

The grooves to either side of the counterbores extend through the face portions to the opposite ends of the blocks to form additional channels through which a fluid may flow. These channels may be closed off by welding when the block is utilized for certain specific purposes to control the flow of fluid through the exchanger.

Each accumulation chamber is closed at one end and open at the opposite end to form the inlet and outlet connections. A cap plate, formed of the same metal as heat exchanger, is welded to the exchanger over one end of the accumulation chamber. The cap plate closes off that end of the accumulation chamber to retain one of the fluids

within the heat exchanger, preventing any mixing of the fluid flowing through the exchanger and the fluid flowing around the exchanger.

The exchanger formed of these modules can be positioned within an enclosure to allow a fluid flowing through the enclosure to pass through a number of flow slots defined by the fins on the exchanger in order to cool or be cooled by the fluid flowing through the passages in the heat exchanger. The fluid flowing through the heat exchanger passages may be oil, transmission fluid, coolant, or any other fluid to be cooled or used as a cooling fluid. The fluid is charged to and removed from the heat exchanger through a pair of hoses attached to the inlet and outlet connections of the exchanger. Each hose is sealingly engaged with a nipple joined to the exchanger over the inlet and outlet connections of the exchanger. Each nipple is usually formed of the same metal as the enclosure so that the nipples may be welded to the enclosure wall creating a reliable seal about the periphery of the nipple to prevent mixing or leakage of the respective fluids.

However, as the nipples and the exchanger are formed from dissimilar metals, the nipples cannot be welded directly to the inlet and outlet connections due to the aforementioned problems associated with dissimilar metal welded connections. In order to overcome these problems, the nipple is retained in sealing engagement over the inlet and outlet connections of each fluid accumulation chamber by a peripheral retainer formed of the same metal as the exchanger. The retainer includes an opening in its center that is inserted around the nipple to hold the nipple in engagement with the heat exchanger over the connections. The retainer is then welded directly to the face portion of the heat exchanger to reliably secure the nipple in sealing engagement with the heat exchanger.

In certain arrangements, the heat exchanger is positioned within an enclosure formed of a second metal in a sealed manner due to a the novel exchanger assembly and method of securing an end piece formed of a second metal to the heat exchanger. The assembly and method enables a reliable welded connection to be made between the end piece and the enclosure and between the exchanger and the end piece to prevent mixing of one fluid with the other.

The construction of the novel exchanger assembly also allows the fluid to be cooled to flow through the passages in the exchanger or around the passages, depending upon the type of fluid that is to be cooled and the use to which the exchanger is put. Therefore, the exchanger can also be positioned in an exhaust system for use as an exhaust cooler, where the cooling fluid flows through the passages to cool hot exhaust gases flowing through the exchanger around the passages. In another embodiment of the invention where the heat exchanger is used as a transformer oil cooler, the grooves extending through the face portions on either side of the lateral openings are not welded shut when the longitudinal passages are closed. The open grooves allow a cooling fluid, such as air, to flow through the exchanger in the same manner as the previous embodiment, as well as along the grooves parallel to the longitudinal passages and perpendicular to the original cooling fluid flow, providing additional capacity for heat transfer in the exchanger.

In accordance with a presently preferred embodiment of the invention for use as a diesel engine exhaust cooler, the heat exchanger includes a housing having an open end, a closed end and a pair of spaced first fluid openings that are disposed adjacent to the open end. A cap is secured to the housing over the open end and includes a central dividing wall that separates the cap into a pair of chambers, each chamber being in fluid communication with one of a pair of second fluid openings in the cap. A plurality of unitary heat exchange modules, of a block-like construction described above, are disposed within the housing in fluid communication with the first fluid openings and the second fluid openings. The modules are grouped to define a pair of separate cells each of which is aligned with one of the chambers in the cap. The through bores in each group of heat exchange modules are in fluid communication with one of the second fluid openings, and the slots defined by the toothed fins in the modules are in fluid communication with the first fluid openings permitting fluid flow along and transverse to the slots.

The housing and the heat exchange modules are preferably made of aluminum and the cap is made of steel, preferably stainless steel. The housing and heat exchange modules are easily removed from the stainless steel cap with bolted connections of which two embodiments are disclosed.

The construction of the preferred embodiments also utilize a unique construction and arrangement of header plates to separate the two fluids and to position the unitary modules that form the heat exchanger assembly. The modules are formed with narrowed necks at each end defining the end of the pattern of toothed fins, the necks also surrounding and defining the end openings to the through bore. A header plate for each end of the plurality of modules forming an assembly is sized to receive the necks of the modules and to interconnect and hold the modules in the assembly. Each header plate is supported at the end of the assembly on the end-most fins and closes the space defined by the fins between the necks of adjacent modules. The peripheral edge of each header plate generally coincides with the outer periphery of the assembly of modules. Sealing material is used to provide fluid tight seams between each header plate opening and the respective module neck that extends therethrough. Each header plate is connected to the assembly with welds. Finally, a tank having a continuous outer edge is connected to the peripheral edge of each header plate along a fluid tight joint. In one embodiment, a first fluid inlet connection is made to one of the tanks to direct a first fluid through the longitudinal bores in the modules and into the other tank. A housing is provided that extends between the header plates and at least partially encloses the assembly and an inlet is provided in the housing for directing a second fluid into and through the slots between the modules of the assembly. An outlet is also provided for directing the second fluid from the housing and is positioned with respect to the inlet to cause the second fluid to flow through the assembly in a direction along the slots and transverse thereto through the spaces defined by the tooth-shaped fins. Preferably, the housing comprises a walled enclosure that includes a pair of side walls and a pair of end walls, and the heat exchanger further comprises a pair of module assemblies within the housing, a partition wall separating the assemblies which partition wall extends between opposite side walls and is connected along an edge between the side walls to one of the header plates. An open passage is provided between an opposite partition wall and the other header plate to provide a connection for the second fluid between the two assemblies. The inlet and the outlet for the second fluid are positioned in the housing walls on opposite sides of the partition wall and adjacent to the header plate to which the partition wall is connected.

In a further variation, a separator plate divides the one tank into an inlet chamber for the first fluid and an outlet chamber for the first fluid. The first fluid inlet connection opens into the inlet chamber, and a first fluid outlet connection is provided in the outlet chamber for directing the first fluid from the heat exchanger.

In a further embodiment, which is particularly adaptable for use in more conventional automotive radiator applications, the slots that are cut in the faces of the modules do not extend the full length of the module, but rather terminate on both ends to form unslotted module ends. Each of the ends, in turn, terminates in a shoulder that leads to a neck surrounding and defining an end opening to the module throughbore. The header plate is supported on the shoulders of adjacent modules forming the assembly and closes the space between the necks of adjacent modules. In this embodiment, the header plate comprises a generally flat mean body portion in which are formed the openings for the necks of the modules. The main body portion is surrounded by a peripheral outer rim that encloses the plate body portion and forms a sealant contaminant chamber. The chamber is adapted to receive a pourable sealant to a depth sufficient to fill the chamber and cover the body portion of the header plate. The header plate is permanently secured to the module assembly with spaced welds between the unslotted ends of the modules and the undersurface of the plate body opposite the containment chamber. The outer edge of the tank is dimensioned to extend into the containment chamber and the sealant therein to form the fluid tight joint. Spaced tack welds are them provided along an interface between the rim of the containment chamber and the edge of the tank. In a typical automotive application, the slots define air flow passages through the assembly and each of the tanks includes a fluid transfer connection.

BRIEF DESCRIPTION OF THE OF THE DRAWINGS

Fig. 1 is a front elevation view of a heat exchanger assembly constructed according to the present invention placed in a bottom collection tank of a conventional radiator;

Fig. 2 is a cross-sectional view along line 2-2 of Fig. 1;

Fig. 3 is a cross-sectional view along line 3-3 of Fig. 2;

Fig. 4 is a cross-sectional view along line 4-4 of Fig. 2;

Fig. 5 is a partially broken away isometric view of a second embodiment of the present invention used as a transformer oil cooler;

Fig. 6 is a cross-sectional view along line 6-6 of Fig. 5;

Fig. 7 is a side elevation view of the transformer oil cooler of Fig. 5 attached to a transformer;

Fig. 8 is a partially broken away cross-sectional view of the heat exchanger of Fig. 5 showing a turbulator plate disposed within a passage of the exchanger;

Fig. 9 is a cross-sectional view along line 9-9 of Fig. 8;

Fig. 10 is a partially broken away side elevation view of a third embodiment of the heat exchanger assembly of the present invention utilized as an exhaust cooler;

Fig. 11 is a cross-sectional view along line 11-11 of Fig. 10;

Fig. 12 is an isometric view of a fourth embodiment of the heat exchanger assembly of the present invention utilized as an exhaust cooler;

Fig. 13 is a cross-sectional view along line 13-13 of Fig. 12;

Fig. 14 is a cross-sectional view along line 14-14 of Fig. 13;

Fig. 15 is a cross-sectional view along line 15-15 of Fig. 13;

Fig. 16 is a partial sectional view of a heat exchanger module utilized in the embodiment of Fig. 12;

Fig. 17 is a schematic view of the system in which the exhaust cooler of Fig. 12 is utilized;

Figs. 18A-18C are additional embodiments of the heat exchanger modules of the present invention;

Fig. 19 is a top plan view of the alternative module construction of Fig. 18a secured to a header plate;

Fig. 20 is a top plan view of the heat exchanger module of Fig. 18C secured to a header plate;

Fig. 21 is a cross-sectional along line 21-21 of Fig. 19;

Fig. 22 is a cross-sectional view along line 22-22 of Fig. 21;

Fig. 23 is a partial sectional view similar to Fig. 21 illustrating an alternate configuration of the heat exchanger modules of Fig. 19; and

Fig. 24 is a cross-sectional view along line 24-24 of Fig. 23.

Fig. 25 is a horizontal sectional view of another embodiment of the Fig. 12 exhaust cooler take on line 25-25 of Fig. 26.

Fig. 26 is a vertical sectional view take on line 26-26 of Fig. 25.

Fig. 27 is a front elevation view of a further embodiment of the invention with a portion shown in section.

Fig. 28 is a horizontal section through the heat exchanger taken on line 28-28 of Fig. 27.

DETAILED DESCRIPTION OF THE INVENTION

With reference now to the drawing figures wherein like reference numerals designate like parts throughout the disclosure, the present invention is a heat exchanger indicated generally at 20 and illustrated in Fig. 1. The exchanger 20 is positioned in a bottom collection tank 22 of a conventional radiator 24 for use as an oil cooler. In this arrangement, the oil flows through the exchanger 20 via a pair of openings 21 in a side wall 23 of the tank 22. The exchanger 20 transfers heat from the oil flowing through the exchanger 20 in a direction shown by arrows A to a coolant fluid passing through the collection tank 22 and around the cooler 20 in a direction shown by arrows B before recirculating the oil back to the automobile engine.

Referring now to Figs. 2-5, the exchanger 20 is made up of a plurality of modular elements 26 that are assembled to form a body 25 of the exchanger 20. An exchanger 20 having this general construction is disclosed in Dierbeck U.S. Patent 5,303,770, which is herein incorporated by reference. Each element 26 is preferably made from an elongate extruded aluminum block 28. The block 28 is generally rectangular in cross-section, having a pair of wide faces 30 joined by a pair of narrow faces 31. Two parallel, longitudinal passages 32 having flattened or oval cross-sections extend completely through the block 28 along the wide faces 30. Each block 28 also includes a number of V-shaped grooves 33 extending along the wide faces 30 of the block. The grooves 33 increase the available surface area over which heat transfer can occur and reduce the amount of aluminum used to form the block 28.

A series of parallel fins 34 are formed on both wide faces 30 of the block 28 to overlay the passages 32, with adjacent pairs of fins 34 defining slots 36 between the fins 34. The fins 34 are formed by cutting the slots 36 across the grooves 33 at predetermined

intervals so that the fins 34 extend generally perpendicular to the axes of the passages 32 have a sawtooth profile. The outer edges 38 of the fins 34 lay coplanar with the wide face 30 in which they are formed.

The body 25 of the exchanger 20 is formed by stacking the blocks 28 together in face-to-face contact with the outer edges 38 of the fins 34 on adjacent blocks 28 directly abutting one another. The fins 34 and slots 36 on the blocks 28 in the assembled body 25 define inner fluid flow passages 40 between adjacent blocks 28 which are twice the height of the fins 34 in length, and as wide as the slot 36 between adjacent fins 34. The fins 34 and slots 36 located on the blocks 28 at each end of the exchanger 20 define a series of outer air flow passages 42 which are half the length of inner air passages 40.

The opposite ends of each block 28 include grooved, unslotted face portions 44 on both wide faces 30. A lateral opening 46 is centered in and extends through each of the face portions 44. The opening 46 intersects both of the passages 32 extending through the block 28. When the blocks 28 are assembled to form the body 25 of exchanger 20, the openings 46 in the blocks 28 define a pair of accumulation chambers 47 for collection of the fluid flow at an inlet end 48 and an outlet end 50 of the exchanger 20.

In order to prevent fluid flowing through the passages 32 from leaking around the lateral openings 46, a counterbore 52 is disposed about each lateral opening 46. The counterbore 52 is located in each face portion 44 on either side of the lateral opening 46, and extends into the base portion 44 for a depth greater than the grooves 33. In one counterbore 52 is disposed a rectangular section annular insert 54. The rectangular insert 54 is preferably made of aluminum and is press fit into the counterbore 52 to effectively prevent any fluid communication between the grooves 33 intersecting the counterbore 52 and the lateral opening 46.

Opposite the rectangular insert 54, a second aluminum insert having a L-shaped cross-section 56 is placed within the opposite counterbore 52. An O-ring 58 is positioned within the L-shaped insert 56. When adjacent blocks 28 are positioned in a face-to-face arrangement, the O-ring 58 extending around the lateral opening 46, one block 28 sealingly engages the rectangular insert 54 of the adjacent block 28. In this manner, the O-ring 58 and rectangular insert 54 provide a liquid seal about the lateral openings 46. To secure each insert 54 and 56 in position, an adhesive may be placed between the inserts 54

and 56 in the counterbore 52, or, should the inserts 54 and 56 be formed of aluminum, small seam welds may be positioned about the circumference of each insert 54 and 56. In an alternative embodiment, the L-shaped insert 56 and O-ring 58 may be replaced by a single resilient grommet (not shown) that sealingly engages the rectangular insert 54 positioned on an adjacent block 28.

When positioned in this face-to-face arrangement, the grooves 33 on adjacent blocks 28 which extend through the face portions 44 on either side of the counterbores 52 form a number of diamond-shaped channels 60. The channels 60 allow the fluid flowing around the passages 32 to flow longitudinally through the exchanger 20 in a direction parallel to the passages 32, increasing the heat transfer capacity of the exchanger 20.

As shown in Fig. 4, to close off the passages 32 in outer edges 62 of face portions 44, a number of plugs 64 are positioned within each end of passages 32, completely obstructing the ends of each passage 32. The plugs 64 may comprise permanent welds, elastomer plugs, or aluminum plugs secured in place with an adhesive. These plugs may also cover the channels 60 to restrict fluid flow around the passages 32 in a single direction or the channels may be covered by a second set of plugs 66.

To form the body 25 of the exchanger 20 from blocks 26, the preferred means for securing adjacent blocks 28 together is to weld the outer edges 62 of face portions 44 of adjacent blocks 28 to one another. However, the blocks 28 may also be connected by placing an adhesive (not shown) on adjacent face portions 44, either alone, or in connection with some type of positioning arrangement. In either arrangement, the welds or adhesive used also form the plugs 66 used to close the channels 60 extending through the face portions.

Another arrangement that can be utilized to form the exchanger 20 is that disclosed in the Dierbeck patent, i.e., using tie rods (not shown) that are insertable through openings (not shown) in the face portions 44 of each block 28 and secured to the exchanger 20 by nuts (not shown) threadedly mounted at both ends of the rods.

To completely enclose the interior of the exchanger 20, the face portion 44 at each the end of accumulation chamber 47 opposite the outermost O-ring 58 is closed off by attaching a rectangular cap plate 68 over the opening 46, as shown in Figs. 2, 3 and 4. The cap plate 68 is formed of aluminum and includes a circular depression 70 in its

center. The depression 70 receives an O-ring 72 similar to O-rings 58 located in the U-shaped inserts 56 of each face portion. The cap plate 68 is attached to the face portion 44 by a weld 74 between the cap plate 66 and the face portion 44 to sealingly engage the O-ring 72 in depression 70 with the rectangular insert 54 about the counterbore 52 in the face portion 44.

Looking now at Figs. 2 and 3, attached over the inlet end 48 and outlet end 50 opposite the cap plates 68 are tank connections 76 used to attach the exchanger 20 to the tank 22. Each connection 76 includes a steel nipple 78 that is generally cylindrical in shape, including a channel 80 extending through the nipple 78. The nipple 78 also includes a flange 82 extending radially outward from one end of the nipple 78. The diameter of the channel 80 in nipple 78 is approximately equal to the diameter of the opening 46 in face portions 44. The flange 82 has a diameter greater than that of the L-shaped insert 56 in the face portion 44. Therefore, when the nipple 78 is attached to the exchanger 20 over the inlet end 48 or the outlet end 50 to form the connection 76, the flange 82 rests on the face portion 44 and sealingly engages the O-ring 58 positioned in the insert 56 in the face portions 44 of the inlet end 48 or outlet end 50 of exchanger 20.

The nipple 78 is secured to the exchanger 20 to form the connection 76 by a retainer 84. Retainer 84 is formed of aluminum, is generally rectangular in shape, and includes a nipple opening 86 in its center. The diameter of the opening 86 is slightly greater than the exterior diameter of the nipple 78 to allow the nipple 78 to be inserted through opening 86 in retainer 84. Also, on one side of the retainer 84, the opening 86 includes a circular recess 88. When the retainer 84 is positioned over nipple 78 on the face portion 44, the recess 88 receives and engages the flange 82 on nipple 78, pressing the flange 82 into engagement with the O-ring 58. Furthermore, as the retainer 84 is formed of the same metal as the exchanger 20, the retainer 84 can be secured directly to the exchanger 20 by a weld 90 between the retainer 84 and the face portion 44.

In each connection 76, the nipple 78 is sealingly secured over the inlet 48 or outlet 50 of the exchanger 20 without the need for welding the nipple 78 directly to the exchanger 20, avoiding the problems typically found when welding dissimilar metals together. Also, when the exchanger 20 is placed within the collection tank 22 of the radiator 24, the nipples 78 extend through the openings 21 in side wall 23 of the tank 22

for connection to a pair of hoses (not shown) that carry the heated oil from the engine to the cooler 20, and from the exchanger 20 back to the engine. To secure the exchanger 20 and within the tank 22 so that the hoses can be connected to the nipples 78, a weld 92 is formed between the nipple 78 and the tank 22. Because the nipples 78 and tank 22 are formed of the same metal, similarly to the retainers 84 and the exchanger 20, the weld 92 between each nipple 78 and the tank 22 is not subject to differential thermal expansion. Therefore, the tank connections 76 allow the aluminum exchanger 20 to be positively joined with the steel tank 22 to cool oil flowing from the engine and avoid the problems normally associated with attaching dissimilar metals without having to provide and connect multiple intermediate pieces in order to form a proper seal between the exchanger 20 and tank 22.

A second embodiment of the present invention is illustrated in Figs. 5-9. In this embodiment, the exchanger 20 is secured to a transformer 94 and utilized as a transformer oil cooler. In this embodiment, the exchanger 20 is substantially identical to the first embodiment to allow air to circulate through the exchanger 20 in a direction perpendicular to the fluid flow through the passages 32 along the channels 60 and also in a direction parallel to the direction of fluid flow through the passages 32 between the fins 34. Thus, an increased amount of air is able to flow through the exchanger 20 around the passages 32 to cool the oil flowing through the passages from the transformer 94.

As shown in Fig. 7, the exchanger 20 is attached to one side of the transformer 94 such that the inlet end 48 is disposed directly beneath the outlet end 50. This orientation is required as the oil flows between the transformer 94 and exchanger 20 by a convection current indicated at C generated by the heating of the oil within the transformer 94 and the cooling of the oil as it flows upwardly along the exchanger 20. To secure the exchanger 20 in this arrangement with the transformer 94, the nipples 78 in each connection 76 are attached to the transformer 94 by welds 96 between the nipple 78 and the transformer 94.

Referring now to Figs. 8 and 9, the passages 32 within the exchanger 20 may include additional elements to enhance the heat transfer capability of the exchanger. The first structure is a turbulator plate 98 that is insertable into the passage 32 prior to the closure of the passage 32 by the end plug 54. The turbulator plate 96 is formed of a thin piece of metal or other rigid material that has a length and width slightly shorter than the

corresponding dimensions of the passage 32. The plate 98 includes a number of raised portions 100 disposed over the surface of the plate. The raised portions 100 extend from both sides of the turbulator plate 98 and serve to agitate the flow through the passage 32, allowing the fluid to more uniformly contact the exterior of the passage 32 in order to more effectively transfer heat from the fluid flowing within the passages 32. The raised portions 100 give the turbulator plate 98 a height slightly greater than the height of the passage 32 such that the inner edges of passages 32 engage the tips of the raised portions 100 when the turbulator plate 98 is inserted into the passage 32. The turbulator plate 98 is thus rigidly retained within the passage 32 while in operation.

Alternatively, in an embodiment not shown in the figures, the turbulator plate 98 may be formed of a plurality of thin individual strips of a rigid material that are interwoven to form a generally flat plate having a number of raised portions distributed about both the surfaces of the plate.

The second structure of the exchanger 20 that increases the capacity for heat transfer of the passages 32 is a plurality of generally U-shaped grooves 102 disposed along the passage 32 and extending in the direction of the fluid flow through the passage 32 as shown in Fig. 9. The grooves 102 are located about the entire surface of the passage 32 and greatly increase the surface area of the passage 32 over which heat transfer from the fluid may occur. Furthermore, though the turbulator plate 98 and U-shaped grooves 102 are discussed with respect to the use of exchanger 20 as a transformer oil cooler, the two structures may also be utilized in other embodiments to increase the heat transfer capacity of an exchanger 20 used for a purpose other than as a transformer oil cooler.

A third embodiment of the present invention is shown in Figs. 10 and 11 where the exchanger 20 is utilized as an exhaust cooler. In this embodiment, engine coolant flows through the passages 32 of the exchanger 20 to cool hot exhaust gases flowing from the engine through the passages 40 defined by the slots 36. The construction of the exchanger 20 in this embodiment is similar to that disclosed in the first embodiment in that the exchanger 20 is formed of a number of blocks 28 secured to each other in a vertically stacked arrangement. The exchanger 20 also includes a pair of end plates 104 welded over the wide faces 30 of the uppermost and lowermost blocks 28 forming the exchanger 20. The plates 104 serve to enclose the fins 34 located on the uppermost and lowermost

blocks 28 to enable the exchanger 20 to direct heated exhaust gases flowing from the engine through the slots 36 formed by the fins 34 on each block 28.

The end plates 104 and face portions 44 provide attachment points for the attachment of a pair of exhaust pipe connectors 106 to the exchanger 20. The connectors 106 serve to position the exchanger 20 within an exhaust system for a vehicle. The connectors 106 include a circular end portion 108, an outwardly extending angled portion 110, and a generally rectangular end portion 112. Opposite the angled portion 104, the rectangular end portion 112 includes a number of flanges 114 extending outwardly from each side of the rectangular end portion 112. The flanges each include a pair of mounting openings (not shown) that receive fasteners 118 to secure the exhaust pipe connectors 106 to the exchanger 20. Each of the flanges 114 extends along an entire side of the rectangular end portion 112, with the flanges 114 at the top and bottom of the exchanger 20 extending parallel to the direction of exhaust gas flow through the exchanger, and flanges 114 on either side of the exchanger 20 extending perpendicularly to the direction of air flow. Thus, the fasteners 118 inserted through the mounting openings in the flanges contact the end plates 104 at the top and bottom of the exchanger, and the face portions 44 on either side of the exchanger 20 without intersecting the lateral openings 46 within the face portions 44. Opposite the rectangular end portion 112, the circular end portion 108 is dimensioned to be slightly larger than an exhaust pipe 120 connected to an automobile engine. The circular end portion 108 is connected to the exhaust pipe 100 in a conventional sealed manner to prevent heated exhaust from flowing between the pipe 120 and connector 106 without flowing through the exchanger 20. Also, the grooves 33 passing through the face portions 44 are completely sealed by a number of plugs or welds (not shown) extending across the grooves to prevent exhaust from flowing outwardly through the grooves without passing entirely through the exchanger 20.

Each connector 106 also includes a number of baffles 122 disposed within the angled portion 110 and rectangular end portion 112. The baffles 122 extend into the connector 106 perpendicularly to the direction of air flow through the connector and serve to act as a muffler by dampening the noise generated by the air flow through the exhaust system.

Referring now to Figs. 12-17, a fourth embodiment of the invention is illustrated. In this embodiment, the diesel exhaust cooler 124 includes a cap 126 secured to a housing 128. The cap 126 is generally rectangular in shape and includes a flat top end 130 from which extend opposed pairs of side walls 132 and end walls 134. The side walls 132 and end walls 134 define an open end 136 opposite the top end 130 which is encircled by a peripheral flange 138. The flange 138 includes a number of bolt holes 140 extending around the flange 138 through which are inserted bolts 142 for connections to be described below.

The cap 126 also includes an interior baffle 144 extending downwardly parallel to end walls 134 between the midpoints of the side walls 132. The baffle 144 separates the cap 126 into a pair of chambers 146, each of which is in fluid communication with one of a fluid inlet 148 or a fluid outlet 150 disposed diagonally opposite from one another on opposed sides of the cap 126.

Looking specifically now at Fig. 13, the housing 128 includes a top portion 152 secured to a bottom portion 154. The top portion 152 includes a pair of side walls 156 joined at opposed ends by a pair of shorter end walls 158. The side walls 156 and end walls 158 define an enclosure 160 in which is disposed a partition wall 162. The partition wall 162 is in alignment with the baffle 144 on the cap 126 and is positioned within the enclosure 160 between the midpoints of the side walls 156. The partition wall 162 divides the enclosure 160 within top portion 152 into a pair of cells 164. The partition wall 162 also permits fluid communication between the respective cells 164 because the wall 162 has a length shorter than that of walls 156 and 158, defining a passage 165 at the lower end of the top portion 152 between the cells 164. The passage 165 enables a coolant fluid which enters the top portion 152 through a fluid inlet 166 disposed in the end wall 158 of the top portion 152 in fluid communication with the adjacent cell 164, to flow between the cells 164. This allows the coolant fluid to contact each of the heat exchanger modules 170 within the top portion 152 before flowing out of the cooler 124 through a fluid outlet 167 disposed in the end wall 158 opposite the fluid inlet.

Referring now to Figs. 13-16, each cell 164 encloses an assembly 168 of heat exchanger modules 170. Each module 170 is similar to the modules or blocks 28

described with respect to previous embodiments. Each module 170 includes a body 172 having toothed fins 184 formed in opposite faces and a pair of longitudinal throughbores 176 extending the length of each module 170 between the faces 174 and in a direction transverse to the fins 184. The modules 170 are preferably formed from aluminum extrusions that include the throughbores 176 and V-shaped grooves 178 extending parallel to the bores along the exterior of each of the faces 174. The grooves 178 are subsequently cut laterally to form slots 182 which extend across the faces 174 perpendicular to the grooves 178 to define the saw-toothed fins 184. The modules are slotted along their full lengths and, at opposite ends, the endmost fin 185 end at necks 180 which define the bores 176.

The modules 170 can be secured to one another and to the top portion 152 to form the assembly 168 in a conventional manner such as by using bolts, a high temperature adhesive, or welds. However, most preferably, the modules 170 are held in position within the respective cells 164 of top portion 152 of the housing by a top header plate 186 and a bottom header plate 188 disposed at opposite ends of the top portion 152. Each header plate 186 and 188 is secured to the top portion 152 by welds 189 and includes a plurality of openings 190 dimensioned to receive the necks 180 at the ends of each module 170 in order to position and securely retain each module 170 within the housing 128. The necks 180 can be then secured within the openings 190 of the header plates by any conventional means, such as an adhesive, but are preferably secured by welds 192. Between adjacent modules 170, the header plates cover the endmost fins 185 (see Fig. 16) and also cover and close the diamond-shaped passages 187 defined by adjacent saw toothed fins 184. Thus, the header plates also serve to assure leak proof separation of the two fluids (exhaust and coolant, for example) flowing through the head exchanger 124. The header plates may further be used to adjust the module-to-module spacing within an assembly comprising a cell 164.

Top header plate 186 has a peripheral dimension approximately equal to the peripheral dimension of the flange 136 on cap 126. Furthermore, the top header plate 186 includes a number of bolt holes 194 spaced about the periphery of the top header plate 186 that are alignable with the bolt holes 140 in the peripheral flange 136 on cap 126. As a result, when the top header plate 186 is secured to the housing 128 by welds

189, and the cap 126 is positioned on the top header plate 166 over the housing 128, the holes 140 in peripheral flange 136 of cap 126 align with the holes 194 in the top header plate 186 such that the bolts 142 can be inserted through the respective holes 140 and 194 and secured therein with nuts 198. Furthermore, in order to prevent fluid from leaking out of the cooler 124 between the cap 126 and top header plate 186, a gasket 200 is disposed between the top header plate 186 and peripheral flange 136. The gasket 200 is formed of a resilient material but is preferably an exhaust gasket with a boiler sealant applied to the exterior of the gasket 200.

Opposite the cap 126, the bottom portion 154 of housing 128 is secured to the bottom header plate 188. In one embodiment, as best shown in Fig. 15, the bottom portion 154 includes a bottom wall 202 from which extend upwardly opposed pairs of side walls 204 and end walls 206. The side walls 204 and end walls 206 define an open upper end 208 which is positioned in fluid communication with the modules 170 extending through the openings 190 in the bottom header plate 188. To retain the bottom portion 154 on the bottom header plate 188, continuous weld 210 is formed between the open upper end 208 of the bottom portion 154 and the bottom header plate 188.

Referring also to Figs. 25 and 26, there is shown another embodiment of an exhaust cooler 211 of the present invention. In this embodiment, the exhaust cooler includes an upper cap 212 and a unitary lower housing 213. Rather than utilizing a separate bottom portion as in the previously described embodiment, the housing 213 includes extended length side walls 214 and end walls 215. The walls 214 and 215 define a lower end opening 216 that is closed by an end plate 217 welded to the opening 216. The interior space above the end plate 217 and the bottom header plate 188 defines the volume provided by the bottom portion 154 of the Fig. 13 embodiment.

The interior of the housing 213 is provided with a modified partition wall 218 that separates the upper portions of the cells 164 as previously described. The central portion of the partition wall 218 includes a vertically extending bolt tube 220 extending the full vertical length of the wall. The upper cap 212 also includes a modified baffle plate 221 that is provided with an integral cylindrical stud 222. When the cap 212 is installed atop the housing 213, the cylindrical stud 222 is aligned with the bolt tube 220

in the lower partition wall 218. The lower end plate 217 is centrally bored to receive a long connecting bolt 223 which extends upwardly through the bolt tube 220 in the partition wall 218 with the upper end of the bolt threaded into a tapped bore in the lower end of the stud 222. The inner surface of the end plate 217 is provided with a pair of stiffening ribs 224 to maintain the rigidity of the end plate 217 when the connecting bolt 223 is threaded tightly to secure the cap 212 on the housing 213. The lower edge of the cap 212 is provided with a widened end flange 226 which receives the upper edge of the housing 213 with a suitable sealing gasket 225 interposed therebetween. The cap 212 and housing 213 are readily detachable from one another simply by removing the connecting bolt 223.

Referring now to Figs. 18-24, three alternative embodiments for the heat exchange modules 170 used in the present invention are illustrated. In Fig. 18A, a module 170 includes U-shaped grooves on opposed faces 174 of the module that extend parallel to a single throughbore 176 disposed within the module 170. The U-shaped grooves, in conjunction with the slots that extend perpendicularly across the grooves 244, define fins 248 which can be positioned within the U-shaped grooves 244 on adjacent modules 170 to form the overlapping heat exchanger module configuration shown in Fig. 19. This configuration enables an exhaust cooler 124 constructed in this manner to be smaller in size than the cooler 20 shown in Figs. 12-17 due to the nesting of the modules 170 within one another. Further, the effectiveness of the cooler 124 is not reduced because a higher amount of turbulence is generated in the flow of the cooling fluid past the fins 248. This increase is graphically illustrated in Figs. 21-24 where the overlap of the fins 248 on adjacent modules 170 and the flow path of the cooling fluid between the fins is shown for both aligned and staggered arrangements of the fins 248. The increased turbulence increases the thermal contact of the cooling fluid with the module 170 insures heat transfer between the heated fluid flowing within the throughbores 176 and the cooling fluid comparable to that achieved with the previous embodiment for the cooler 124.

A similar configuration for the modules 170 is shown in Fig. 18 in which the U-shaped grooves 244 are cut deeper into the body of the module 170 in order to increase the surface area available for heat transfer and to reduce the amount of material the heat

must be transferred through on each module 170. This further increases through the amount of heat that can be transferred from the heated fluid in the throughbore 176 to the coolant fluid flowing past the fins 249.

A fourth embodiment of the module 170 is shown in Fig. 18C. In this embodiment, the module 170 includes a number of U-shaped grooves 244 formed on the opposite faces 174 of the module 170. The grooves 244 on opposite faces 174 of the module 170 are offset from one another such that the fins 250 on one face 174 are in alignment with the grooves 244 on the opposite face 170. This configuration enables the modules 170 to be positioned with the modules 170 in either a staggered arrangement similar to Fig. 19, or in an aligned arrangement as shown in Fig. 20. The arrangement of the modules 170 shown in either Fig. 19 or 20 positions the fins 250 of adjacent modules 170 is such that laminar flow of the cooling fluid past the fins 249 or 250 is disrupted and made highly turbulent to increase the thermal contact of the cooling fluid with the fins.

In operation and referring also to Fig. 17, the cooler 124 is connected to the exhaust system 230 of an automobile. Exhaust from an engine 232 passes along an exhaust pipe 234 to a Y-junction 236 where a portion of the exhaust is directed at the junction 236 to a muffler 238. The remaining portion of the exhaust flows along the other leg of the junction 236 to the exhaust cooler 124 (or 211). The exhaust enters the cooler 124 through fluid inlet 148 and into the cap 126. The baffle 144 directs the incoming exhaust downwardly into the throughbores 176 in each module 170 disposed in the cell 164 beneath the chamber 146 that is in communication with the fluid inlet 148 as indicated by arrows A in Figs. 13, 15 and 16. Simultaneously, a coolant fluid flowing from a coolant source 240 (such as the engine cooling system) enters the housing 128 through the fluid inlet nozzle 166. The coolant flows into the cell 164 disposed directly beneath the chamber 146 into which the exhaust is flowing and flows along the slots 182 in each module 170 between the fins 184 and through the V-shaped grooves 178 in a direction transverse to the fins as shown by arrows B in Figs. 15 and 16. As the exhaust flows through the throughbores 176, the modules 170 are heated by the exhaust, and the coolant flowing past the fins 184 removes this heat to, in turn, cool the exhaust.

The exhaust and coolant each flow downwardly through the respective flow paths in the cell 164 until each respective fluid is directed at or near the bottom of the cell into the adjacent cell 164. For the exhaust, the bottom portion 154 of the housing receives the incoming exhaust from the first cell 164 and directs it in a direction shown by arrow C in Fig. 13 upwardly into the throughbores 176 of the modules 170 in the adjacent cell 164. The coolant flows downwardly within the cell 16 until it reaches a level within the housing 128 below the lower edge of the partition wall 162 and then passes through the passage 166 into the adjacent cell 164 as shown by arrow D in Fig. 13. The pressure of the incoming exhaust and coolant forces each of these fluids respectively upwardly along the throughbores 176 and past the fins 184, respectively. The exhaust flows upwardly through the thoughbores 176 until the exhaust reaches the second chamber 146 from which the now cooled exhaust is expelled from the cooler 124 through the fluid outlet 150 as indicated by arrow E in Fig. 13. The now-cooled exhaust is then directed to a turbocharger 242 for the engine 232. The heated coolant rises to a level coincident with the outlet 167 and flows outwardly through this nozzle for recirculation to the coolant tank 240 as shown by arrow F in Fig. 13. The generally parallel flow paths of the exhaust and coolant, first downward through one cell 164 and then upward through the other cell 164 in a U-shaped path, allows for a very compact construction which can be easily modified to provide varying package sizes.

The exhaust coolers 124 and 211 described above are particularly well suited to be used as air charge coolers for a turbocharger of a diesel engine. For this application, the top caps 126 and 212 of the respective embodiments are preferably made of stainless steel to withstand the high temperature of the exhaust gases entering the inlet 148. The incoming exhaust gas temperature may be as high as 1200°F. The exhaust cooler of either embodiment is designed to cool the exhaust gas to a temperature of about 300°F as it exits the outlet 150. The lower housing 128 (or 213), including the heat exchange module assemblies 168 mounted therein, are preferably made of aluminum. The lower temperature of coolant through the housing, which may be supplied directly from the engine cooling system, maintains the temperature of the aluminum components sufficiently low to prevent thermal degradation. If necessary, the entire aluminum lower

housing and heat exchange assemblies 168 are readily replaceable. In the embodiment of Figs. 12 and 13, replacement of the lower section requires the removal of the mounting bolts 142. In the embodiment shown in Figs. 25 and 26, replacement of the lower housing 213 is much more simply accomplished by removal of the single long connecting bolt 223.

In addition to its principal intended use as an air charge cooler, either embodiment of the exhaust cooler 124 or 211 could also be adapted for use as a transmission oil cooler or other similar automotive application. As indicated above, in the primary intended use as an exhaust cooler, the incoming diesel exhaust may have a temperature as high as 1200°F. Nevertheless, it has been found that the aluminum components having a somewhat lower softening temperature remain protected by the flow of coolant therethrough as described above. However, because diesel exhaust tends to be acidic and may have a detrimental corrosive effect on aluminum, in some applications it may be desirable to coat the longitudinal through bores 76 of the module 170, as well as the interior of the bottom portion 154 and other surfaces contacted by the exhaust, with an acid resistant coating.

In Figs. 27 and 28, there is shown an embodiment of the present invention that is particularly adapted for use as an automotive radiator or similar cooling system for an internal combustion engine. The heat exchanger 243 is made of an assembly of extruded aluminum modules 244, each of which is similar to the previously described module 170, except that the pattern of slots 245 cut in the outer face portions of the modules to form the fins 246 do not extend the full length of the module 244. Instead, each module has unslotted ends 247 where there are no fins. Each of the opposite module ends 247 terminates in a shoulder 248. Each shoulder 248, in turn, surrounds a central axially extending neck 250 which is similar to the neck 180 in the previously described embodiment.

A header plate 251 includes a flat main body portion 253 which is provided with a series of openings 252 for receipt of the necks 250 of the module assembly. The underside of the flat body portion 253 of the header plate rests on the shoulders 248 of the modules. Each header plate is secured in position to the module assembly with a

series of spaced welds 254 connecting the underside of the flat body portion of the header plate 251 to the unslotted ends 247 of the modules.

The header plate 251 has an integral peripheral outer rim 255 that surrounds the center body portion to form, on the upper end of the heat exchanger 243, a sealant containment chamber 256. After the assembly of modules 244 has been secured to the header plate 251 with the welds 254, a pourable sealant 257 is poured in a uniform layer over the bottom of the chamber 256. The sealant 257 provides fluid tight seams between the openings 252 in the header plate and the necks 250 extending through the openings. A tank 258 having a continuous lower edge 259 sized to fit closely within the outer rim 255 of the header plate is pressed into the sealant layer 257 before the sealant hardens to form a fluid tight joint between the tank and the header plate. The sealed joint is secured by a series of tack welds 260 between upstanding tabs 261 on the header plate and the side walls 262 of the tank.

The lower header plate 251 and tank 258 are installed in the same manner with the heat exchanger inverted. To complete the heat exchanger 243 for a typical automotive application, the bottom tank is provided with an inlet connection and the top tank 258 is provided with an outlet connection and a fill opening with a pressure cap 265. Suitable mounting brackets 266 may be conveniently attached to the outsides of the outermost modules 244 as by welding.

One suitable sealant material is an RTV silicone adhesive. This material will withstand temperatures as high as 600°F (315°C). The sealant will thus retain its sealing capability in a typical automotive cooling system application.